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Paleomagnetism of mafic dikes from the Avalon Peninsula, eastern Newfoundland

M.K. Seguin, E. Gahé and M.S. Khalfi

*Paleomagnetic Laboratory, Faculty of Science and Engineering
Université Laval, Quebec, City, P.Q., Canada*

As part of a major study of the Avalon zone in eastern Newfoundland, we describe the paleomagnetism of two series of dikes located in the Bauline and Colliers-Harbour Main areas, respectively. Detailed alternating field (AF) and thermal experiments performed on these dikes indicate that they are characterized by two significantly different mean directions of magnetization: SE++ ($D = 153^\circ$, $I = +62^\circ$; $K = 46$, $N = 12$ sites) and SW ($D = 217^\circ$, $I = +58^\circ$, $K = 58$, $N = 12$ sites) with corresponding paleopole positions at A (4°N , 34°W ; $d_p, d_m = 8^\circ$, 10°) and C (2°N , 81°W ; $d_p, d_m = 6^\circ$, 9°). Antipoles A and C are located in southerly latitudes, and a comparison with other poles of Avalonian rocks from New Brunswick, Nova Scotia and Newfoundland indicates a Silurian to Siluro-Devonian age for these dikes. Poles A and B are interpreted as representing rapid apparent polar wander with respect to eastern Newfoundland during Silurian time. Two components of magnetization, corresponding to two distinct geological events, are observed in the dikes investigated and this situation favours the following geological scenario for the evolution of the Avalon microcontinent: (a) intracratonic rift zone resulting in long-lived Late Hadrynian and Cambrian continental extension, (b) a very late phase of distension in separating miniplates during Silurian and Early Devonian time.

Dans le cadre d'une étude d'envergure de la zone d'Avalon menée dans l'est de Terre-Neuve, nous décrivons le paléomagnétisme de deux séries de dykes situées dans les régions de Bauline et de Colliers-Harbour Main respectivement. Des expériences détaillées de désaimantation par champ alternatif (CA) et par lavage thermique démontrent que deux directions moyennes de l'aimantation caractérisent les dykes: SE++ ($D = 153^\circ$, $I = +62^\circ$; $K = 46$, $N = 12$ sites de prélèvement) et SO ($D = 217^\circ$, $I = +58^\circ$, $K = 58$, $N = 12$ sites de prélèvement) avec des paléopôles correspondants aux positions A (4°N , 34°O ; $d_p, d_m = 8^\circ, 10^\circ$) et C (2°N , 81°O ; $d_p, d_m = 6^\circ, 9^\circ$). Les antipôles A et C se situent à des latitudes méridionales et par comparaison avec d'autres pôles de roches avaloniennes du Nouveau-Brunswick, de la Nouvelle-Ecosse et de Terre-Neuve, on attribue aux dykes un âge Silurien à Siluro-Dévonien. On interprète les pôles géomagnétiques A et B comme le résultat de déplacements rapides du pôle par rapport avec l'est de Terre-Neuve durant le Silurien. On observe dans ces dykes deux composantes de magnétisation, correspondant à deux événements géologiques distincts. Ceci suggère le scénario suivant pour expliquer l'évolution du microcontinent Avalon: (a) un rift intracratonique qui se traduit par une longue période d'extension continentale depuis l'Hadrynien tardif jusqu'au Cambrien; (b) du Silurien jusqu'au début du Dévonien, une phase tardive de distension lors de la séparation des miniplaques.

[Traduit par le journal]

INTRODUCTION

The eastern segment of the Appalachian orogen is largely underlain by Late Precambrian rocks. These rocks were labelled "Avalonian", after the Avalonian Peninsula of eastern Newfoundland (Kay 1967, Poole 1967) where they are typically exposed. Detailed studies in the eastern Avalon Peninsula have been carried out by Papezik (1972), Nixon and Papezik (1979) and King (1979). Sys-

tematic mapping programs of the Avalon Zone were first undertaken by Rose (1952), Hutchinson (1953) and McCartney (1956, 1967). The Precambrian stratigraphy was elucidated subsequently by Misra (1969), Brückner and Anderson (1971), Hughes and Brückner (1972), King *et al.* (1974), Anderson *et al.* (1975) and Strong (1979). The Avalon Peninsula was affected by two principal orogenies, a Late Precambrian "Avalonian orogeny" (Lilly 1966) and the "Acadian" orogeny of Middle to Late Devonian age (Strong 1979). Different tectonic models

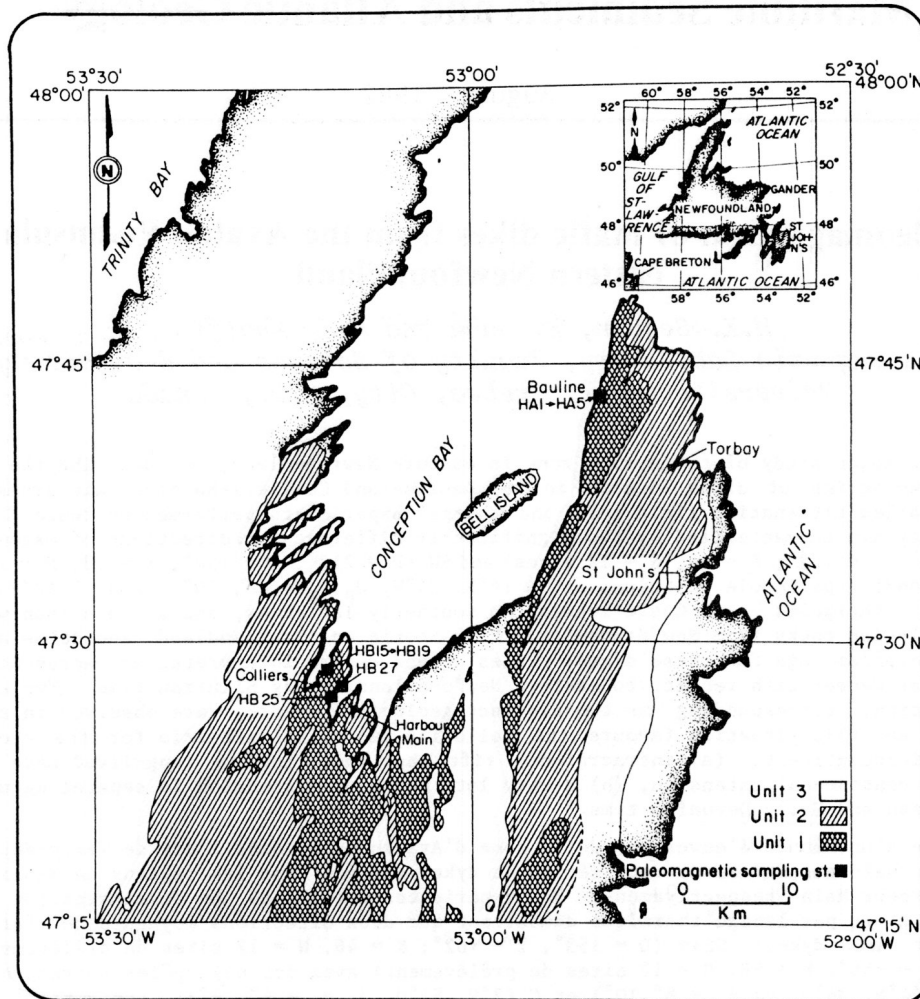


Fig. 1 - Distribution of paleomagnetic sampling sites (HA and HB) in eastern Newfoundland. Unit 1 = Harbour Main Group, Unit 2 = Conception Group, Unit 3 = upper sedimentary Group.

have been proposed for the origin of the Avalon mini-continent: 1) island arc (Hughes and Brückner 1972, Rast *et al.* (1976); 2) subduction and Basin and Range-type rifting (Schenk 1978); Strong *et al.* 1980; and 3) continental extension and rifting (Rankin 1976).

Precambrian rocks similar to the ones encountered in the Avalon Zone occur throughout the Appalachian orogen, in Nova Scotia, New Brunswick, eastern Massachusetts, southeastern United States (Carolina State Belt, Williams 1979) and on the eastern side of the Atlantic, i.e. Wales, Brittany, the Iberian Peninsula, Czechoslovakia and Turkey, as well as in northeast Africa (Choubert 1935, Schenk 1978, Cogné 1972,

Rast *et al.* 1976, Strong 1979, Williams 1979).

GEOLOGICAL SETTING

In the Whitbourne (Colliers-Harbour Main) and Torbay-Bauline map areas (Fig. 1), the Late Precambrian rocks of the Avalon Zone are subdivided into three groups: 1) Harbour Main Group, 2) Conception Group, and 3) an upper sedimentary Group, all of which are overlain, in turn, by a small zone of Lower Cambrian sedimentary blocks. The Harbour Main Group is composed of marine and terrestrial volcanics, the Conception Group of volcanoclastic sedimentary rocks and the upper sedimentary Group of shallow continental sedimentary

strata (Brückner and Anderson 1971, Williams and King 1979, King 1979, Williams 1979). The Harbour Main Group is intruded by the Holyrood plutonic series south of the study area (McCartney 1967). Generally, all the lithological groups are weakly metamorphosed to the sub-greenschist facies (Nixon and Papezik 1979). Contact metamorphic effects near and within the Holyrood plutonic rocks have been recognized (McCartney 1967).

Small basic dikes (diabasic gabbro, diabase and trap) cut the Harbour Main Group in the Torbay map area (Rose 1952) and both Harbour Main and Conception Groups as well as Cambrian sedimentary units (up to lower Middle Cambrian) in the Whitbourne map area (McCartney 1967). In the Colliers Bay area (Fig. 1), these dikes cut all other Late Precambrian rocks including porphyrites and rhyolite sills (Nixon and Papezik 1979). The dikes present chilled margins to the rocks cut, they cut the Hadrynian rocks in all directions, they generally have a subvertical dip and their thickness vary from a few decimeters to tens of meters. No significant geological difference (mineralogical and textural) is observed between HA and HB dikes. The dikes are apparently older than Late Devonian - Early Carboniferous.

Consequently, the HA and HB mafic dikes sampled in the Bauline and Colliers-Harbour Main areas, respectively, have a possible age span extending from the Middle Cambrian to the Late Devonian. No radiometric data are available on these dikes.

SAMPLING PROCEDURE

Some 61 oriented samples (159 specimens were collected at 12 different sites (5 in HA and 7 in HB); the orientation was taken with a Brunton or a sun compass. The number of samples per site varied from 5 to 7 and the number of specimens per sample between 2 and 5. The majority of the samples were collected on the chilled margins of the dikes. The oriented hand samples were later cored in the laboratory. The locations were chosen with reference to

detailed geological maps published by Rose (1952), Hutchinson (1953), McCartney (1967), Nixon and Papezik (1979) and King (1979). Efforts were made to select sites where there was adequate exposure and where the structural geology was simple and best understood. Great care was taken to avoid altered material. The locations of the sampling sites are shown on Fig. 1.

EXPERIMENTAL PROCEDURE

Equipment Used

The direction and intensity of remanent magnetization were measured with digital spinner magnetometer (model DSM-1) manufactured by Schonstedt Inst. Co. (sensitivity = 10^{-4} Am⁻¹). Alternating field (AF) demagnetization was carried out by using a demagnetizer built at Laval University which has a maximum peak-to-peak intensity of 90 millitesla (mT). Its performance was improved by adding 3 large concentric mu-metal cylinders around the solenoid (Seguin 1975) and a Schonstedt AF specimen demagnetizer (model GS D-1). Thermal treatment of the specimens was done in a field-free demagnetizer (model TSD-1) manufactured by Schonstedt Inst. Co. The amount of residual ambient field present is 5 nT in the demagnetizer, and 10 nT in the electrical oven.

Remanent Orientation and Intensities

Individual specimen natural remanent magnetization (NRM) directions of HA and HB dikes (Fig. 2), although characterized by wide scatter caused by some positively and one negatively inclined shallow remanence, have a pronounced deviation away from the Present Earth's Field (PEF) ($D = 334^\circ$, $I = +71^\circ$) at the site localities. This indicates that HA and HB dikes carry some ancient remanence especially since the directions of the remanence of the few specimens (10-15%) that lie close to the PEF were found to move away from those initial directions during AF or thermal treatment. It is also noticeable that the majority of the directions of the remanence are lo-

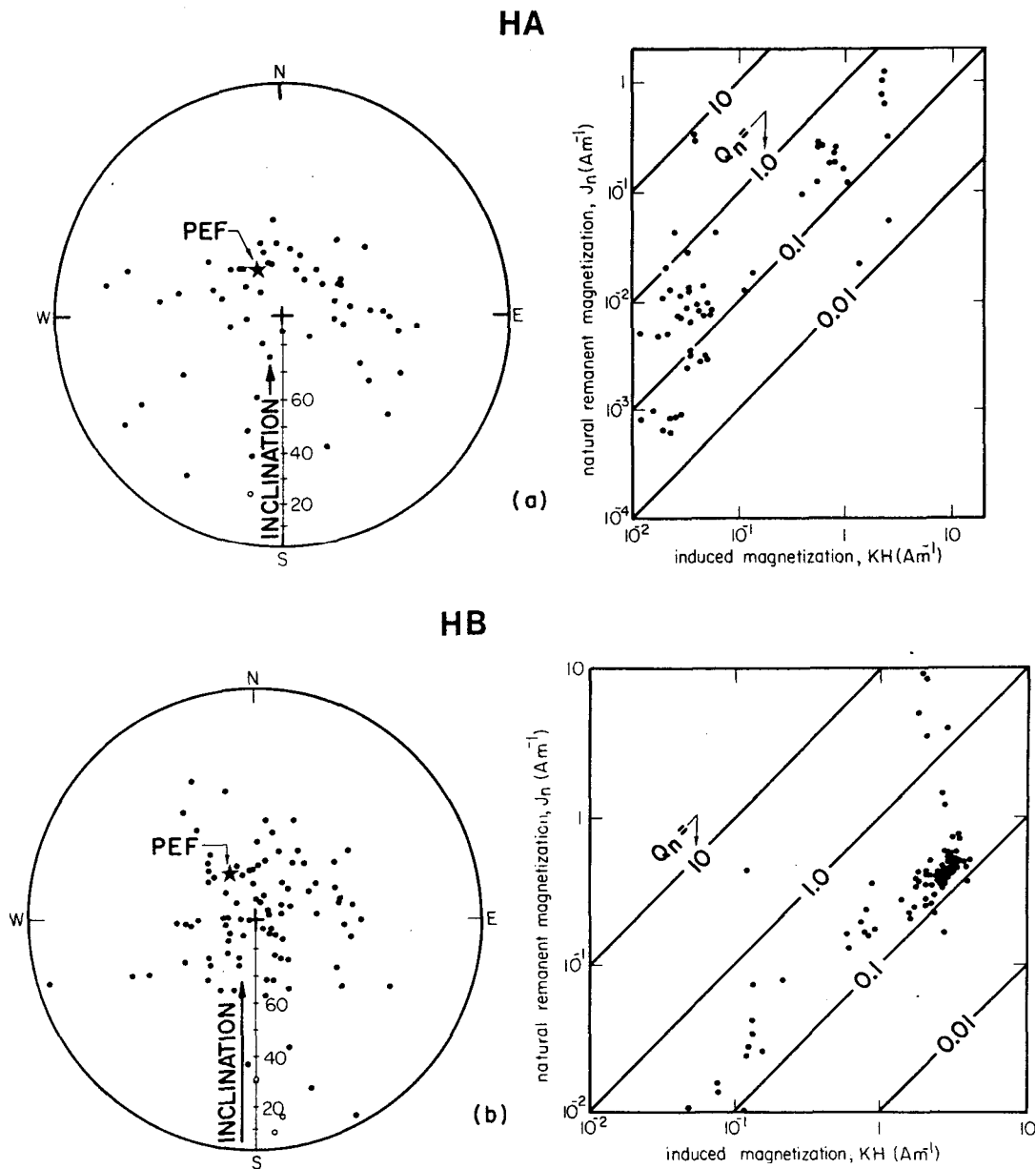


Fig. 2 - Individual specimen NRM directions plotted on Wulff net for HA (2a) and HB (2b) dikes (left). Solid (open) circles represent projections on lower (upper) hemisphere. The star represents the present earth's field (PEF) at the sampling locality. Plots of corresponding intensity of NRM (J_n in Am^{-1}) against the induced magnetization (KH in Am^{-1}) with resulting slope lines indicating the values of Koenigsberger ratio, Q_n (right).

cated in the southern quadrants on the stereonet. The wide scatter in NRM with occasional dual polarity of remanence is, therefore, indicative of the presence of both low and high coercivity components. The intensities of NRM (J_n) vary from 10^{-2} to 4 Am^{-1} with values of the Koenigsberger ratio ($Q_n = J_n/KH$)

between 0.07 and 8, with most ratios between 0.2 and 0.7 (Fig. 2).

The Q_n values for both HA and HB dikes are similar; they are mainly located in the range 0.1 - 1.0. This observation suggests that they have more or less the same age and that they are probably consanguineous. The NRM orientations of

HA and HB dikes are also quite similar. Those directions which are not located close to the PEF plot preferentially in the two southern quadrants. The inclinations are predominantly downward.

PRELIMINARY DEMAGNETIZING STUDIES

AF Demagnetization

For the preliminary AF study at least five specimens per HA and HB site were demagnetized in 14 steps up to 100 mT, and vector diagrams (Zijderveld 1967) were used in the subsequent analysis. For 95% of the HA (HB) samples, the intensities of magnetization at/or before the 60 (30) mT treatment had fallen to less than 10% of the NRM intensity. In almost 45% of the samples, the measure-

ments indicated acquisition of spurious magnetizations at higher demagnetizing fields (70-100 mT) for HA and 30-50 mT for HB. Remanence behaviour during AF treatment typical of most samples from the five HA dike sites are shown by three specimens from three different sites. Vector trajectories are linear until stable end-points are reached at higher fields. The linear trajectory for specimen HA 4 - 3.B indicated the presence of two components (Fig. 3). One has a northeasterly directed magneti-

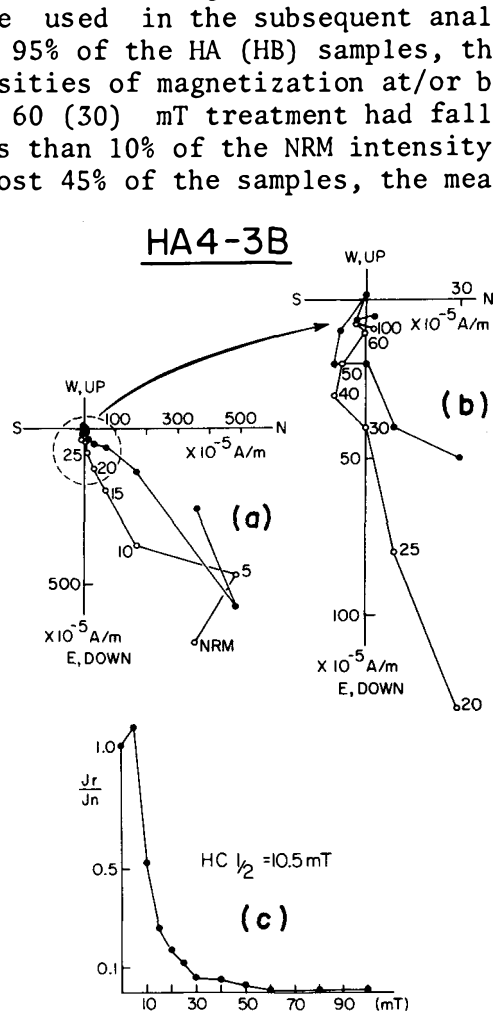


Fig. 3 - Representative orthogonal AF demagnetization diagrams (Zijderveld, 1967) of successive end-points of magnetization vector for the HA4-3.B dike specimen as indicated. Solid (open) circles represent projections on horizontal (vertical) plane. Numbers next to open circles represent the demagnetization steps (mT).

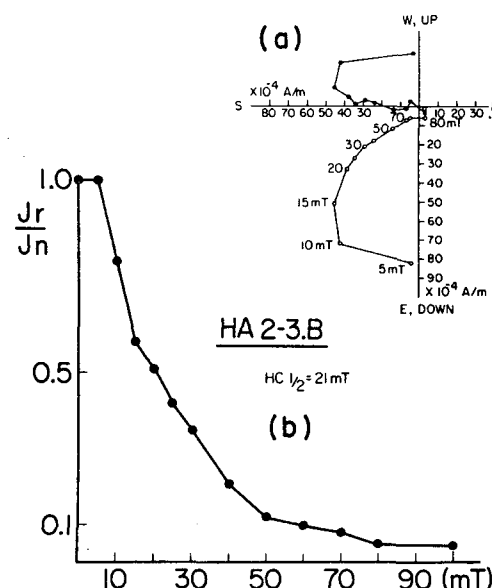


Fig. 4 - Representative orthogonal AF demagnetization diagrams (Zijderveld, 1967) of successive end-points of magnetization vector for the HA2-3.B dike specimen. The other symbols are as in Fig. 3.

zation having an intermediate to steep downward inclination ($D = 50^\circ$, $I = 60^\circ$), which is present in the 5-30 mT range (more generally 20 mT) and it is removed at an AF intensity of 40 mT. It is detected on sites HA-2, -3 and -4. The second component has a southeasterly directed magnetization having an intermediate downward inclination ($D = 125^\circ$, $I = 50^\circ$) which is isolated in the 40-80 mT range. This component is observed on sites HA-2 and -3 (eventually HA-5). The linear trajectory for specimen HA 2-3.B (Fig. 4) is characterized by two linear trajectories representing two

different components. The first component has a southwesterly directed magnetization having an intermediate to steep downward inclination ($D = 230^\circ$, $I = 60^\circ$) which is present in the 0-20 mT range (more generally 10-15 mT) and it is removed above the 30 mT AF intensity level. This component is predominant on sites HA-2 and -3 (eventually HA-5). The second component has a southeasterly directed magnetization having an intermediate downward inclination ($D = 170^\circ$, $I = +40^\circ$) isolated in the 25-60 mT range. Occasionally, and this is the case for specimen HA 2-3.B, a third component is isolated in the high coercivity range (70-100 mT). This third component has a northeasterly magnetized direction with an intermediate downward inclination ($D = 45^\circ$, $I = 35^\circ$). This component is observed on two HA sites only. The linear trajectory for specimen HA 3-1.A (Fig. 5) shows the occurrence of two components. One has a southwesterly directed magnetization with an intermediate to steep downward inclination ($D = 240^\circ$, $I = 60^\circ$)

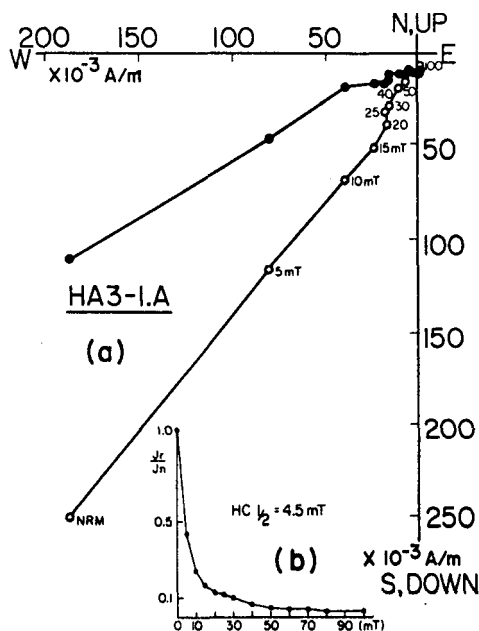


Fig. 5 - Representative orthogonal AF demagnetization diagrams (Zijderveld, 1967) of successive end-points of magnetization vector for the HA3-1.A dike specimen. The other symbols are as in Fig. 3.

present in the 5-60 mT range (generally 45 mT) which is removed at an AF intensity higher than 70 mT. It is present on sites HA-3 and -4. The second component has a magnetization directed to the south with an intermediate downward inclination ($D = 170^\circ$, $I = 45^\circ$) which is observed in the high coercivity range (70-100 mT). This component is occasionally isolated in sites HA-3, -4 and -5.

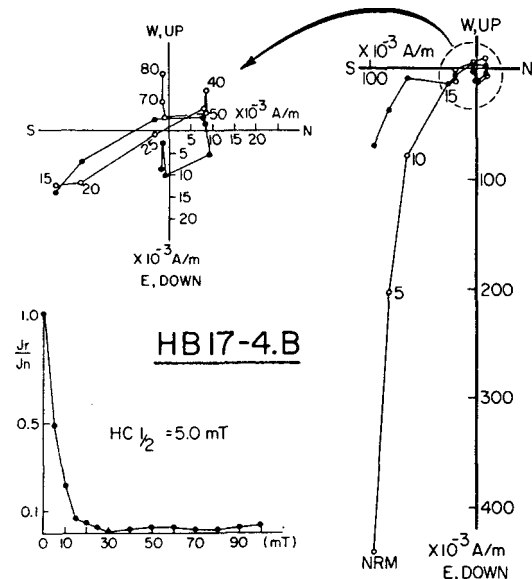


Fig. 6 - Representative orthogonal AF demagnetization diagrams (Zijderveld, 1967) of successive end-points of magnetization vector for the HB17-4.B dike specimen. The other symbols are as in Fig. 3.

Remanence behaviour during AF treatment typical of almost all samples from the seven HB dike sites are represented on Figures 6 and 7 by three specimens from three different sites. Vector trajectories for specimen HB-17-4.B (Fig. 6) indicate the presence of a stable, single component of magnetization with a southeasterly declination and intermediate downward inclination ($D = 160^\circ$, $I = 45^\circ$) in the 10-25 mT range. Acquisition of spurious magnetization above 50 mT renders impossible the extraction of an eventual high coercivity component. This SE intermediate downward component is most common on sites HB-16, -17, -18 and -19. Specimen

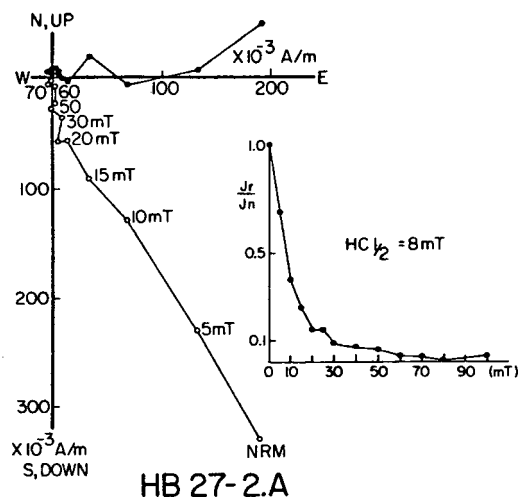


Fig. 7 - Representative orthogonal AF demagnetization diagrams (Zijderveld, 1967) of successive end-points of magnetization vector for the HB27-2.A dike specimen. The other symbols are as in Fig. 3.

HB 27-2.A (Fig. 7) is indicative of another stable, single component which has north-northeasterly directed magnetization with an intermediate to steep downward inclination ($D = 75^\circ$, $I = 60^\circ$). This component is best isolated in the 10-40 mT range and was commonly encountered on sites HB-16, -17, -18, -19 and -27. Finally, specimen HB 19-3.C (Fig. 8a) is characterized by two components of magnetization. The first component has a westerly directed magnetization having a steep to intermediate downward inclination ($D = 270^\circ$, $I = 65^\circ$) which is present in the 0-25 mT range (generally 15 mT) and is removed at an AF intensity of approximately 40 mT. This component is common on sites HB-15, -17, -19 and -25. The second component has a west-southwesterly directed magnetization having a shallow to intermediate downward inclination ($D = 250^\circ$, $I = 25^\circ$). This component, which is isolated in

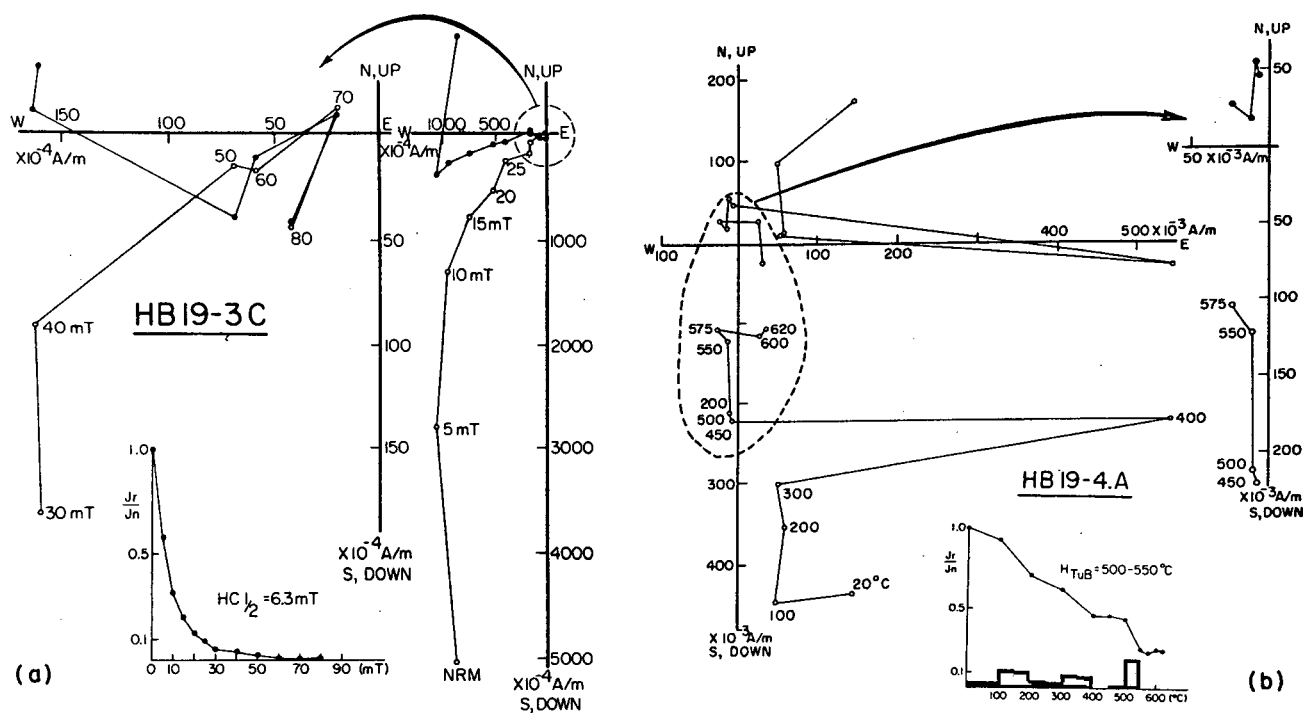


Fig. 8 - Representative orthogonal AF (a), and thermal treatment diagrams (b) (Zijderveld 1967) of successive end-points of magnetization vector for two HB dike specimens as indicated. For specimen HB19-4.A (b), the numbers next to open circles represent the demagnetization steps ($^\circ\text{C}$). The unblocking temperature (T_{UB}) in $^\circ\text{C}$ is indicated below the orthogonal plots. The other symbols are the same as in Fig. 3.

the 40-70 mT range, is very rare because the acquisition of a spurious magnetization interferes with its reliable extraction.

Thermal Treatment

For the preliminary thermal study, at least five specimens per HA and HB sites were demagnetized in 11 steps up to 620°C; vector diagrams were used in subsequent analysis. Most commonly, the unblocking temperature (T_{UB}) (Roy and Lapointe 1978) is located in the 500-575°C range. Typical behaviour of three HA samples during thermal treatment from two different sites is shown in Fig. 9. In the case of specimen HA 3-2.B (Fig. 9a), two components are seen on the linear vector trajectories. The first component is a SSW directed magnetization with a shallow downward inclination ($D = 215^\circ$, $I = 25^\circ$). This component is rarely observed and is definitely secondary - it is detected in the

20-500°C range of specimen HA 3-2.B. The second component is isolated in the 525-575°C range; its orientation is also SSW but its declination is intermediate to steep downward ($D = 215^\circ$, $I = 55^\circ$). This component is common to sites HA-1, -2, -3 and -5. A third component is possibly isolated in the 575-620°C range. Its direction of magnetization is ENE with intermediate to steep downward inclination ($D = 80^\circ$, $I = 60^\circ$). It is unusual to isolate this NE component in the high temperature range. Specimen HA 3-5.1 (Fig. 9b) also depicts two components. The first component has a southern to SSW direction of magnetization with steep downward inclination ($D = 190^\circ$, $I = 75^\circ$).

This direction is present in the 20-350°C range and corresponds to the second component of specimen HA 3-2.B. The second direction of magnetization isolated in this specimen is SSE with an intermediate downward inclination ($D =$

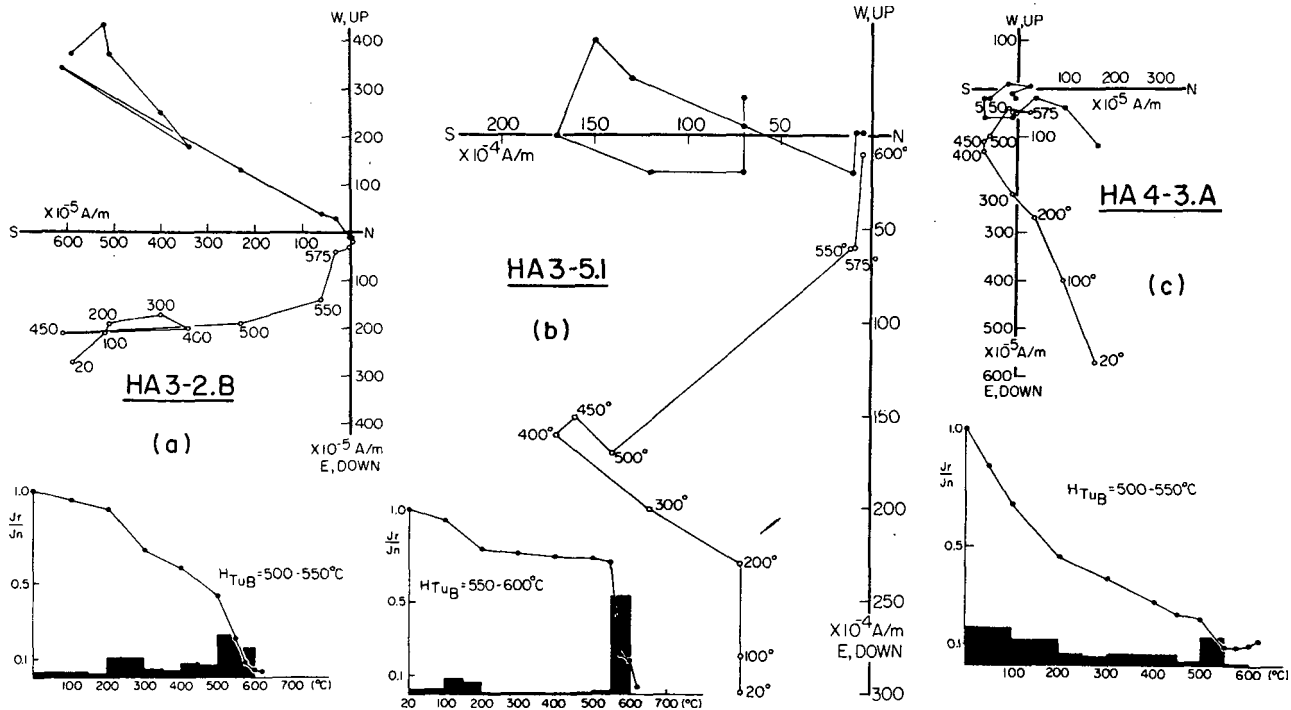


Fig. 9 - Representative orthogonal thermal demagnetization diagrams (Zijderveld 1967) of successive end-points of magnetization vector for three HA dike specimens as indicated. The other symbols are the same as in Fig. 3. The numbers next to open circles represent the demagnetization steps (°C). The unblocking temperature (T_{UB}) in (°C) are indicated below the orthogonal plots.

175°, $I = 50^\circ$). This southeastern direction of magnetization, isolated in the 450-600°C range for specimen HA3-2.B is the most common at all HA dike sites. Two components of magnetization are also detected on specimen HA 4-3.A (Fig. 9c). The first one has a northeasterly directed magnetization with steep downward inclination ($D = 35^\circ$, $I = 75^\circ$) in the 20-400°C range. The second component, a southeasterly directed magnetization having an intermediate to steep downward inclination ($D = 160^\circ$, $I = 65^\circ$), is isolated in the 450-600°C range. This is the most common situation encountered and in particular, at sites HA-2, -3 and -4.

The typical behaviour of one HB sample during thermal treatment from site HB-19 (Fig. 8b) is compared with the one during the course of AF demagnetization. Two components of magnetization are detected on specimen HB 19-4.A. The first component has a northeasterly directed magnetization with steep downward inclination ($D = 80^\circ$, $I = 75^\circ$) and is observed in the 100-400°C range. This is the most common low and/or intermediate temperature component encountered on both HA and HB dike sites. The second component, isolated in the 450-575°C range, has a NNW declination with a steep downward inclination ($D = 320^\circ$, $I = 70^\circ$). The direction of this component corresponds to that of the first component obtained by AF demagnetization (specimen HB 19-3.C, Fig. 8b). This magnetization is encountered on sites HB-15, -17, -19 and -25.

STATISTICAL ANALYSIS OF SITE-MEAN DIRECTIONS

HA and HB dikes site-mean directions for both AF and thermally cleaned results are shown in Table 1. SE++(A), NE(B), SW(C), NW(D), SE++(E) and W remanence directions are observed in either HA or HB dikes and the corresponding group-mean directions based on sites are presented for both groups in the same table. A, B, C, D and E directions are common to both HA and HB dike suites. The W component is obser-

ved in only 2 specimens of the HA and is not significant. The same conclusion applies to the E component for HB dikes. The PEF component is relatively common in the HB dikes, but seldom observed in the HA dikes. As a result of these observations, only the A, B, C and D components are common to both HA and HB sites and thus considered reliable for paleomagnetic investigation. The E component is also significant, but for some HA sites only.

SEQUENCE OF THE COMPONENTS OF MAGNETIZATION

An attempt to classify the acquisition sequence of these components was made based on: a) the coercivity spectrum and unblocking temperature, b) frequency of distribution, c) precision parameter (K) of the mean direction. Based on criterion a) applied to specimens or samples of the different HA and HB sites, it is assumed that the components having the higher coercivity spectra (H_{cr}) and higher unblocking temperatures (T_{ub}) are the oldest. Clearly, this is not always true since the H_{cr} and the T_{ub} depend on the nature of the magnetic carriers. By working out this relationship, the following sequence was established: $B > A > D > E > C$ for the HA sites, where $B > A$ tentatively means older than A, etc. The sequence $B > A$ generally holds for both AF and thermally cleaned specimens; the sequence $A > D > E$ was established from thermally cleaned results alone, whereas the sequence $E > C$ was obtained from AF demagnetized results alone.

The above sequence is exactly the same as for the HA series when component E is removed. Sequence $B \geq A$ was established from both AF and thermally cleaned specimens, while sequence $A > D$ was deduced from AF demagnetized results. Finally, the relationship $D > C$ is observed in both AF and thermally cleaned results.

On the basis of frequency distribution (number of specimens per component for both HA and HB dike series [see Table 1]), the sequence obtained is the fol-

Table 1
STATISTICAL SUMMARY OF SITE-MEAN DIRECTIONS.

Site	SE++ (A)					NE (B)					SW (C)				
	N(n)	D°	I°	K	α_{95}°	N(n)	D°	I°	K	α_{95}°	N(n)	D°	I°	K	α_{95}°
HA-1	4(8)	167	72	110	8.8	1(1)	022	73	-	-	2(3)	223	53	12.1	-
HA-2	4(6)	156	62	19.7	21.2	2(2)	050	58	30.1	-	2(3)	215	59	24.6	25.4
HA-3	5(6)	162	65	38.3	12.5	2(2)	053	69	9.9	-	4(5)	219	44	48.3	13.4
HA-4	4(9)	154	58	72.7	10.8	2(3)	034	57	108	24.3	1(1)	208	74	-	-
HA-5	2(2)	146	71	16.7	-	1(2)	070	80	-	-	2(4)	237	56	51.4	35.3
mean:	5(31)	157	66	153	6.2	5(10)	044	68	50.2	10.9	5(16)	222	57	44.5	11.6
%	41					13					21				
HB-15	2(3)	156	43	57.9	33.3	2(2)*	075	53	100	25.2	2(3)	201	59	774	9.0
HB-16	3(5)	144	69	30.7	22.8	3(3)	047	61	16.9	30.8	3(5)	219	47	55.9	16.7
HB-17	4(5)	143	53	9.7	31.3	4(5)	031	56	10.6	29.7	4(5)	220	48	59.3	12.0
HB-18	4(5)	162	49	19.6	21.4	4(6)	046	57	11.9	27.8	5(7)	229	65	47.3	11.2
HB-19	5(9)	143	65	28.3	14.7	3(6)	045	59	42.6	19.1	2(3)	224	61	29.5	-
HB-25	2(2)	161	54	-	-	1(1)	021	60	-	-	4(6)	200	61	20.9	20.6
HB-27	2(2)	104	75	-	-	2(4)	039	74	59.4	32.2	4(4)	199	67	77.9	10.5
mean:	7(31)	151	59	31	11.0	7(27)	044	61	54	8.3	7(33)	214	59	65	7.5
%	26					21					27				
HA+HB	12(62)	153	62	45.5	6.5	12(40)	044	64	51.9	6.1	12(49)	217	58	57.8	5.8
<hr/>															
	NW (D)					SE+ (E)					W				
	N(n)	D°	I°	K	α_{95}°	N(n)	D°	I°	K	α_{95}°	N(n)	D°	I°	K	α_{95}°
HA-1											1(1)	284	23	-	-
HA-2						1(2)	162	35	-	-					
HA-3	1(1)	296	61	-	-	3(4)	162	32	10.6	40	1(1)	261	12	-	-
HA-4	4(5)	334	55	41.8	14.4	1(2)	168	30	-	-					
HA-5	3(3)	327	73	22.9	26.4										
mean:	3(9)	319	64	34	20.3	3(8)	164	32	438	5.9	2(2)	272	18	22	-
%	12					10					3				
HB-15	2(3)	291	52	26.1	-	1(1)	125	13	-	-	1(1)	350	84	-	-
HB-16											1(1)	299	83	-	-
HB-17	3(3)	321	36	20.4	28.1						3(4)	328	68	27.4	-
HB-18	1(1)	310	43	-	-						3(3)	325	66	58.1	-
HB-19	3(4)	279	55	33.5	21.7						2(2)	340	71	73.5	-
HB-25	2(2)	281	59	7.9	-						3(5)	338	70	123	-
HB-27											2(2)	335	71	66.9	-
mean:	5(13)	299	50	28	14.7	1(1)	135	13	-	-	7(18)	328	78	29	-
%	10					1					15				
HA+HB	8(22)	305	56	25.3	11.3		149	23	12.5	-					

* = Reverse polarity
N = Number of samples
D = Declination

I = Inclination
K = Precision parameter (Fisher, 1953)
 α_{95} = circle of confidence at 95% probability level (Fisher, 1953)

lowing: $A > C > B > D > E$ for HA dikes and $C > A > B > D$ for HB dikes. Finally, when using the largest precision parameter (K) as a criterion, the sequence arrived at is: $A > B > C > D > E$ for HA dikes and $C > A > B > D$ for HB dikes. As the coercivity spectra of many components are superimposed in the same temperature or AF strength range, this mode of classification was eliminated. By comparing the two other modes of classification, it is noted that components A and C are predominant over components B, D and E for both HA and HB dikes. The common denominator obtained is $A > C > B > D > E$.

VECTOR SUBTRACTION OF COMPONENTS

As the number of geological events is rather limited within the small age interval admissible from field evidence, it was clear that too many components of magnetization were isolated for both HA and HB dikes and that some of these components were composite rather than unique. In addition to Zijdeveld diagrams, the vector subtraction technique was used (Roy and Park 1974). The results obtained with the help of vector subtraction indicated that the B(NE) component is composite and obtained by addition of the PEF to the A component in the low temperature range: 200-400°C for some HA sites, and 100-300°C for some HB sites. The same conclusion applies for AF demagnetization - the spectrum is then located in the 5-25 mT range for some HA dikes and 5-10 mT for some HB dikes (see Table 3). Thus, the B component does not represent a single geological event and is eliminated.

SIGNIFICANCE OF D AND E COMPONENTS OF MAGNETIZATION

The D(NW) component in both HA and HB dikes is responsible for only 10% of the frequency distribution of all the components (Table 1). In the case of HA dikes, the D component is encountered on only two sites and their mean direction ($D = 331$, $I = 64$) corresponds closely to the PEF ($D = 334$, $I = 72$). The specimens of HB dikes which con-

tained only PEF magnetization were discarded. Four sites (HB-15, -17, -19 and -25) which contain the D component (mean: $D = 300$, $I = 50$) remained. The D component was never isolated by thermal treatment and so the existence of this component is rather suspect. The D component was usually isolated in a relatively high AF range (20-70 mT, mean 45 mT), and the PEF is most commonly present in the low AF range. These two observations suggest the occurrence of a fictitious D component which is poorly isolated and still contains a large fraction of the PEF magnetization. In conclusion, the D component has no paleomagnetic or geological significance for the HA or HB dikes.

The E(SE) component is encountered in the HA-3 site only with a frequency distribution of 10% (see Table 1). The E component is extracted by AF demagnetization in the higher coercivity range of the spectrum (40-100 mT) but never after thermal treatment. A comparison of AF and thermal treatments in the same samples of HA-3 site shows that thermal treatment which yielded the A component is more efficient on this specific site than AF demagnetization which yielded the E component. This suggests that the E component is not a real one and can be eliminated.

In conclusion, two reliable components (A and C) remain. Considering the variation in their angle of confidence (α_{95}), the components of magnetization are not significantly different in HA and HB dikes. The interpretation given to this situation is the following: HA and HB dikes have the same paleomagnetic signature, they have the same origin and they are of the same age.

PALEOPOLE POSITIONS AND THEIR RELATION TO POLES PREVIOUSLY DETERMINED

The A component ($D = 153$, $I = +62$) yields a paleopole of 4°N in latitude and 34°W in longitude, and the C component ($D = 217$, $I = +58$) a paleopole of 2°N in latitude and 81°W in longitude (see Table 2). Both components have a paleopole near the equator. The

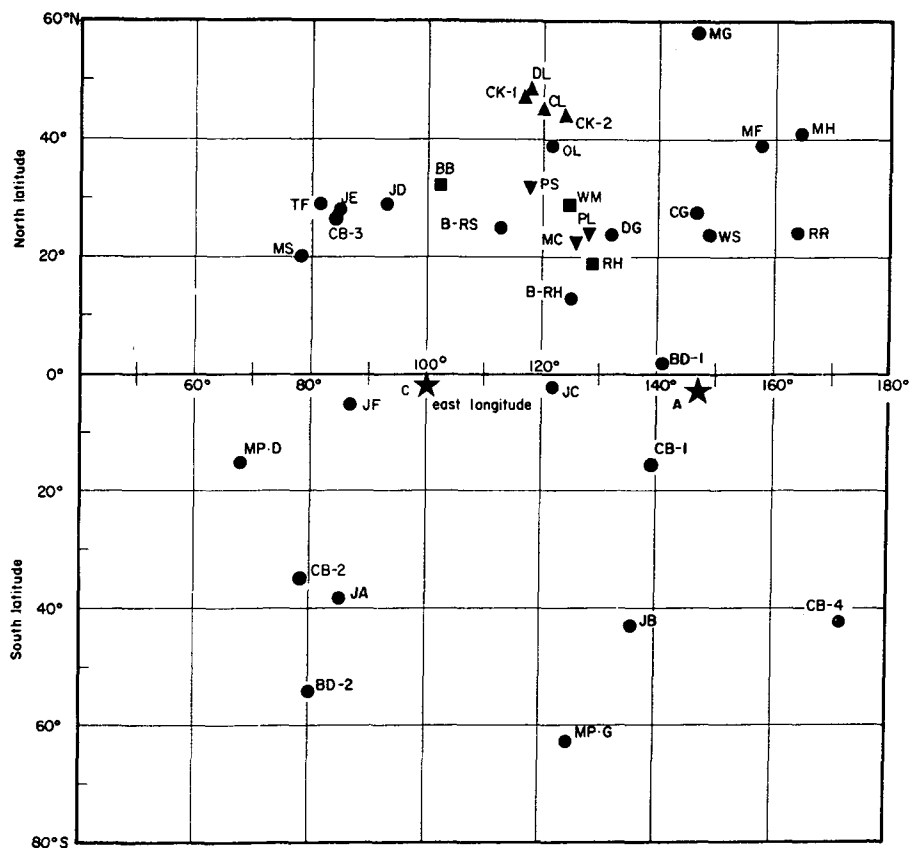


Fig. 10 - Poles obtained from paleomagnetic studies of Silurian and Devonian rock units from Appalachians. Pole symbols are as in Rao *et al.* 1981. The solid squares represent Silurian poles (BB, RH) obtained from interior North America. The solid upright (inverted) triangles represent, respectively, the paleopoles derived from north (south) of Kent and Opdyke's (1978) hypothesized shear zone. The solid circles represent the other Devonian or Siluro-Devonian poles. The stars represent the poles obtained in the present study (Table 2).

same time as ours in the Avalon Zone. More data are needed to prove or disprove this hypothesis. Such a geological situation has a younger equivalent as overprints have been interpreted to have occurred with the rifting and opening of the present Atlantic Ocean in Middle Jurassic time (Seguin *et al.* 1981). This would mean that the Avalon microcontinent was separated from the North American plate during the Silurian period (acquisition of A). As the late Precambrian rocks were deformed during the middle to late Devonian (acquisition of C) Acadian Orogeny (Williams and King 1979) and intruded by Early Carboniferous continental granites, it is clear

that the Avalon microcontinent (AVM) was docking on the North American plate by middle Devonian time. It is thus plausible that the AVM was in compression from Middle Devonian to Middle Jurassic time but in extension before that age span.

One proposed scenario of evolution of AVM is the following:

- 1) formation of an intracontinental basin or continental margin (Poole 1976),
- 2) long-lived Hadrynian continental extension (King 1979),
- 3) local rupture(s) and sea floor spreading by very late Precambrian to early Cambrian (Williams 1979),
- 4) possible occurrence of several

Table 3
VECTOR SUBTRACTION

Specimen No.	T range (°C)	AF strength range (mT)	D (°)	I (°)	$J_{r-n} \times 10^3$ (Am ⁻¹)	ΔD (°)	ΔI (°)	$\Delta J_{r-n} \times 10^3$ (Am ⁻¹)	Specimen No.	T range (°C)	AF strength range (mT)	D (°)	I (°)	$J_{r-n} \times 10^3$ (Am ⁻¹)	ΔD (°)	ΔI (°)	$\Delta J_{r-n} \times 10^3$ (Am ⁻¹)
HA5-2.A	200		60	68	5.07				HA4-3.B		10	38	61	0.87			
						37.1	53.1	1.80							27.1	48.7	0.23
	300		85	73	3.41						15	44	65	0.65			
						2.5	56.3	1.01							19.0	63.7	0.23
	400		116	66	2.65						20	57	64	0.43			
						295.4	15.9	0.71							18.6	61.9	0.16
	450		117	80	2.26						25	78	61	0.28			
															56.8	58.3	0.09
HA4-3.A	200		23	80	0.56						30	89	61	0.19			
						326.1	37.4	0.18									
	300		103	75	0.46				HB18-2.C		0	50	50	7.13			
						356.9	57.7	0.22							284.9	72.5	4.70
	400		140	54	0.32						5	33	14	4.04			
						271.1	26.0	0.08							34.5	-4.4	1.57
	450		161	56	0.27						10	32	25	2.61			
HA4-2.A	100		34	77	0.68				HB18-4.B	200		51	62	5.96			
						20.8	59.6	0.23							36.1	63.2	1.82
	200		66	84	0.47					300		57	61	4.16			
						279.8	61.0	0.33							7.7	-13.4	1.67
	300		92	41	0.27					400		109	69	4.34			
						41.4	-7.3	0.12	HA1-1.A		5	337	76	0.89			
	400		133	51	0.25										303.0	59.2	0.34
HB17-2.B	100		31	82	1.12						10	30	79	0.58			
						314.0	69.3	0.46							338.9	61.7	0.14
	200		351	70	0.72						15	68	79	0.45			
						355.9	38.6	0.17							15.5	66.3	0.09
	300		344	79	0.59						20	92	78	0.37			
						45.2	35.3	0.27									
	400		255	65	0.47												

ΔD = Declination of magnetic vector removed, ΔI = Inclination of magnetic vector removed, ΔJ = Intensity of magnetic vector removed.

separated microcontinents by Cambro-Ordovician time, 5) ongoing extension on detaching miniplates during the lower Paleozoic time up to the middle Devonian.

Our data set pertains to item 5. The previous phases of the scenario may be modified. Williams (1979), amongst others, maintain that the main collision between the North American and the Avalonian continents occurred in the Ordovician. Taking the existing facts into account, the events of the Cambrian to Devonian interval are complex when the geological evidence from Newfoundland to the west of the Avalon Zone is taken into consideration.

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ANDERSON, M.M., BRUCKNER, W.D., KING, A.F. and MAHAR, J.B. 1975. The Late Proterozoic "H.D. Lilly Unconformity" at Red Head, Northeastern Avalon Peninsula, Newfoundland. *American Journal of Science*, v. 27, pp. 1012-1027.

BELL, K., BLENKINSOP, H., BERGER, A.R. and JAYASINGHE, N.R. 1979. The Newport granite: its age, geological setting, and implications for the geology of northeastern Newfoundland. *Canadian Journal of Earth Sciences*, v. 16, pp. 264-269.

BRUCKNER, W.D. and ANDERSON, M.M. 1971. Late Precambrian glacial deposits in Southeastern Newfoundland - a preliminary note. *Geological Association of Canada, Proceedings. A Newfoundland Decade*, v. 24, n. 1, pp. 95-102.

CHUBERT, B. 1935. Recherches sur la

genèse des chaînes paléozoïques et anté-cambriennes. *Rev. Géogr. Phys. Géol. Dyn.*, v. 8, pp. 5-50.

COGNE, J. 1972. Le Briovérien et le cycle orogénique cadomien dans le cadre des orogènes fini-precambriennes. *Notes Mém. Serv. Géol. Maroc*, v. 236, pp. 193-213.

HUGHES, C.J. and BRUCKNER, W.D. 1972. Late Precambrian rocks of eastern Avalon Peninsula Newfoundland - a volcanic island complex: Reply. *Canadian Journal of Earth Sciences*, v. 9, pp. 1059-1060.

HUTCHINSON, R.D. 1953. Geology of Harbour Grace map-area, Newfoundland. *Geological Survey of Canada, Memoir* 275, 43 p.

JAYASINGHE, N.R. and BERGER, A.R. 1976. On the plutonic evolution of the Wesleyville area, Bonavista Bay, Newfoundland. *Canadian Journal of Earth Sciences*, v. 13, pp. 1560-1570.

KAY, M. 1967. Stratigraphy and structure of northwest Newfoundland bearing on drift in the North Atlantic. *American Association of Petroleum Geology Bulletin*, v. 51, pp. 579-600.

KENT, D.V. and OPDYKE, N.D. 1978. Paleomagnetism of the Devonian Catskill red beds: evidence for motion of the coastal New England - Canadian Maritime region relative to cratonic North America. *Journal of Geophysical Research*, 83, pp. 4441-4450.

KING, A.F., BRUCKNER, W.D., ANDERSON, M.M. and FLETCHER, T.P. 1974. Late Precambrian and Cambrian sedimentary sequences of eastern Newfoundland. *Geological Association of Canada, Annual Meeting, Field Trip Manual B-6*, 59p.

KING, A.F. 1979. The Birth of the Caledonides: Late Precambrian rocks of the Avalon Peninsula, Newfoundland, and their correlations in the Appalachian-Orogen. *In the Caledonides in the U.S.A. International Correlation Program (IGCP) Project 27*.

LILLY, H.D. 1966. Late Precambrian and

- Appalachian tectonics in light of submarine exploration on the Grand Bank of Newfoundland and in the Gulf of St. Lawrence. Preliminary Views. American Journal of Science, 264, pp. 569-574.
- MCCARTNEY, W.D. 1956. Argentia, Newfoundland. Geological Survey of Canada Preliminary Map, Paper 55-11.
- 1967. Whitbourne map-area, Newfoundland. Geological Survey of Canada Memoir 341, 135p.
- MISRA, S.B. 1969. Late Precambrian(?) fossils from southeastern Newfoundland. Geological Society of America Bulletin, v. 82, pp. 979-988.
- NIXON, G.T. and PAPEZIK, V.S. 1979. Late Precambrian ash-flow tuffs and associated rocks of the Harbour Main Group near Colliers, eastern Newfoundland: Chemistry and magmatic affinities. Canadian Journal of Earth Sciences, v. 16, pp. 167-181.
- PAPEZIK, V.S. 1972. Late Precambrian ignimbrites in eastern Newfoundland and their tectonic significance. 24th International Geological Congress Proceedings, Section 1, pp. 147-152.
- POOLE, W.H. 1967. Tectonic evolution of Appalachian region of Canada. In *Geology of the Atlantic region*. Edited by E.R.W. Neale and H. Williams. Geological Association of Canada, Special Paper 4, pp. 9-51.
- 1976. Plate tectonic evolution of the Canadian Appalachian region. Geological Survey of Canada Paper 76-1B, pp. 113-126.
- RANKIN, D.W. 1976. Appalachian salients and recesses: Late Precambrian Continental break-up and the opening of the Iapetus Ocean. Journal of Geophysical Research, v. 81, pp. 5605-5619.
- RAST, N., O'BRIEN, B.H. and WARDLE, R.J. 1976. Relationship between Precambrian and Lower Paleozoic rocks of the "Avalon Platform" in New Brunswick, the northeast Appalachians and the British Isles. Tectonophysics, v. 30, pp. 315-338.
- ROSE, E.R. 1952. Torbay map-area, Newfoundland. Geological Survey of Canada Memoir 265, 64p.
- ROY, J.L. and LAPOINTE, P. 1978. Multi-phase Magnetizations: Problems and Implications. Physics of the Earth and Planetary Interiors, v. 16, pp. 20-37.
- ROY, J.L. and PARK, J.K. 1974. The magnetization process of certain red beds: Vector analysis of chemical and thermal results. Canadian Journal of Earth Sciences, v. 11, pp. 437-471.
- SCHENK, P.E. 1978. Synthesis of the Canadian Appalachians. Geological Survey of Canada, Paper 78-13, pp. 111-136.
- SEGUIN, M.K. 1975. Conception et réalisation d'un appareil de désaimantation par champs alternatifs et son utilisation dans les études paléomagnétiques. Abhandlungen der Braunschweigischen Wissenschaftlichen Gesellschaft, XXV, pp. 25-43.
- SEGUIN, M.K., RAO, K.V. and VENUGOPAL, D.V. 1981. Paleomagnetism of parts of the Late Triassic diabase dike system associated with the Trans-New Brunswick aeromagnetic lineament. Accepted for publication in Canadian Journal of Earth Sciences, Dec. 1981.
- STRONG, D.F. 1979. Proterozoic tectonics of northwestern Ganderia: New evidence from eastern Newfoundland. Tectonophysics, v. 54, pp. 81-101.
- WILLIAMS, H. 1979. Appalachian Orogen in Canada. Canadian Journal of Earth Sciences, v. 16, pp. 792-807.
- WILLIAMS, H. and KING, A.F. 1979. Trepassay Map Area, Newfoundland. Geological Survey of Canada, Memoir 389, 24 p.
- ZIJDERVELD, J.D.A. 1967. A.C. demagnetization of rocks: analysis of results. In *Methods in paleomagnetism*. Edited by D.W. Collinson, K.M. Creer, and S.K. Runcorn. Elsevier, Amsterdam, The Netherlands, pp. 254-286.